Constraints on eruption precursors from crustal structure and pore-fluid pressure

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Accelerating rates of occurrence of volcano-tectonic (VT) events show a remarkably restricted range of behaviour before eruptions, independent of magma composition and tectonic setting. The VT events are controlled by fault movement. Restricted patterns of VT behaviour may thus reflect the operation of a common distribution of faults in the crust around a magma reservoir.

The range of precursory VT behaviour has been encapsulated by the empirical Voight criterion (Ref. 1), the limits of which have since been supported by theoretical analyses (Refs 2 and 3). Comparable behaviour has been observed in the laboratory among increasing rates of acoustic emissions (AE) before the bulk failure of rock samples. In detail, however, previous studies have implicitly assumed different loading conditions on the breaking rock. Thus laboratory data typically refer to failure in compression under constant stress or constant strain rate, whereas field data at volcanoes refer to local failure in extension under constant or variable strain rate. The apparent universality of fracturing trends, independent of loading condition, is consistent with precursors being controlled under natural conditions by a structural feature that can develop at length scales from laboratory samples to the crust. This feature must involve discontinuities that (1) are present before a precursory sequence begins and (2) can control rates of precursory fracturing independent of the prevailing stress field. A second, contemporaneous field constraint is that deformation must allow faults to move apart, so that magma can ascend to the surface. Local stress fields must thus satisfy conditions for deformation with a tensile component.

The structural characteristics are satisfied by a Hill-type distribution of discontinuities (Ref. 4), for which a network of fractures, some of which in the field may be filled with magma, are connected to each other by obliquely-oriented faults. Activation of faults in such a network has the potential to induce AE or VT events under stress fields suitable for extension or compression. For crust to fail with a tensile stress component, the applied differential stress cannot exceed about four times its tensile strength (Ref. 5). As a result, pore-fluid pressures greater than hydrostatic must prevail in the vicinity of magma bodies if these are to feed magma to the surface from depths greater than about 2.0-2.5 km.

(1) Voight B (1988) Nature. 332: 125-130; (2) Kilburn, CRJ (2003) J Volcanol Geotherm Res, 125: 271-289; (3) Kilburn CRJ (2012) J Geophys Res, doi: 10.1029/2011JB008703; (4) Hill DP (1977) J Geophys Res, 82: 1,347-1,352; (5) Shaw HR (1980) In Hargeaves RB (Ed.) Chap. 6, Physics of Magmatic Processes, Princeton University Press.